DMTC
DEFENCE MATERIALS
TECHNOLOGY CENTRE

“Material science behind the development of a new, shapeable, boron carbide, armour material”

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ISB29, Edinburgh, May 2016

Acknowledgements

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Fellow researchers:

ADA (2005-2012), CSIRO (2005 to date), VCAMM (2005-2015), as well as the Defence Materials Technology Centre, Melbourne, Australia (2009-2015).

Body Armour Systems and HAPs

Hard Armour Plate
(HAP)

Soft Armour Insert
(SAI)

Tiered, or
Modular

Combat

Body Armour System
(BAS)

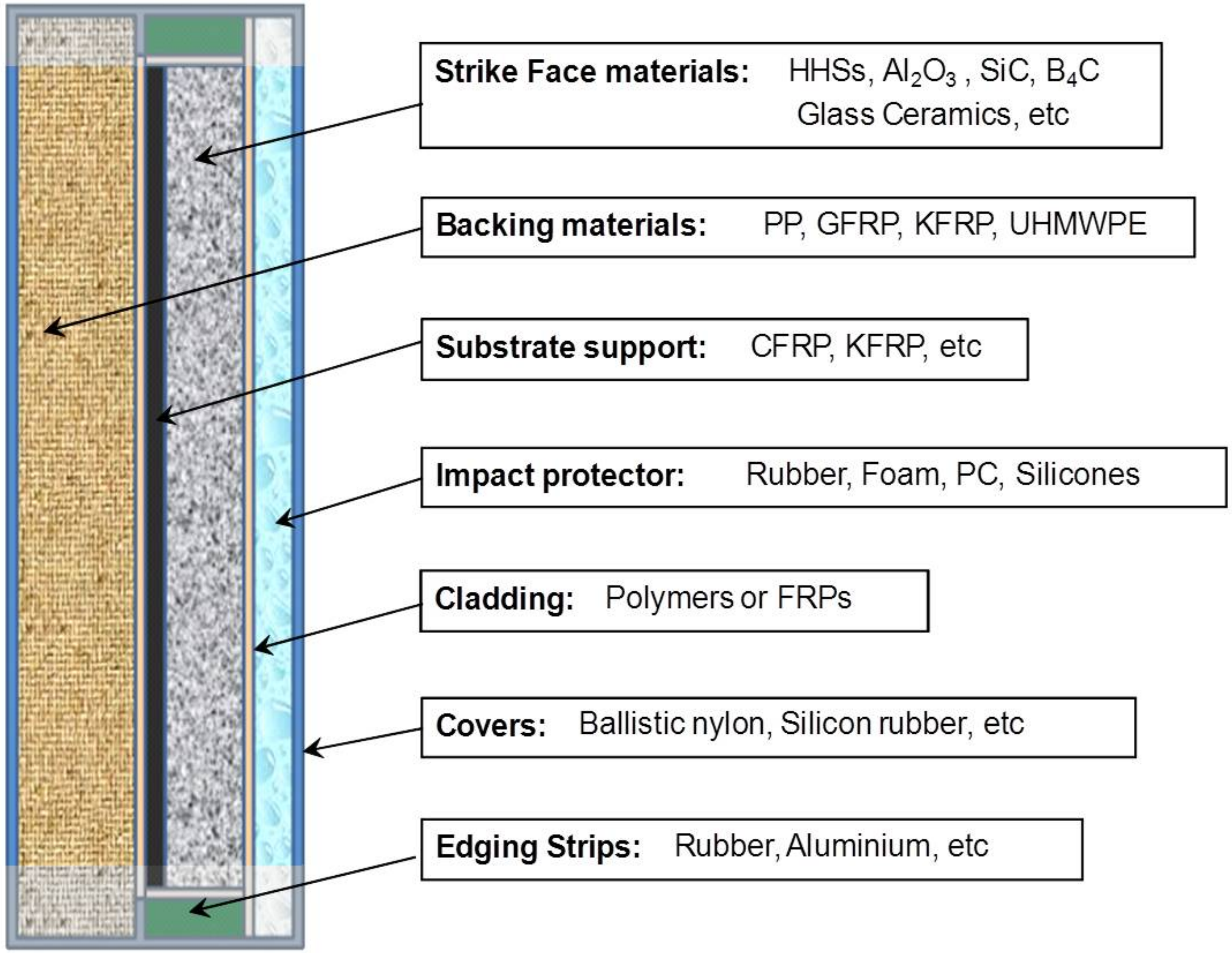
Objectives of 10-year,R&D project

Circa 2005, we recognised the need:

- to rapidly respond to changing User requirements
- for more shapely body armour products
- thinner, lighter weight body armour systems

To develop, LIGHTEST, THINNEST, MOST SHAPEABLE hard armour plate, at an affordable price, utilising most competitive methods of producing both the ceramic element and the HAP, in order to defeat a more realistic threat

Design of HAPs: materials



Design of HAPs: threat

Small Arms Threat		Armour Solutions		
Level	Example	UHMWPE	B_4C + UHMWPE	SiC + UHMWPE
IV++	7.62 x 51 WC core FFV			
IV+	7.62 x 54R API B32			
IV	0.3" AP M2			
III+	7.62 x 39 MSC AK47			
III	7.62 x 51 M80 ball			

Notes: 1. Threat levels are structured around the conventional NIJ 0101.06 levels (III, IV)
2. Examples of threat are not inclusive

Key:

	Excellent ballistic performance
	Good ballistic performance
	Very poor ballistic performance

HAP: manufacturing methods

<u>One Step process:</u>
Autoclave, or Hydroclave

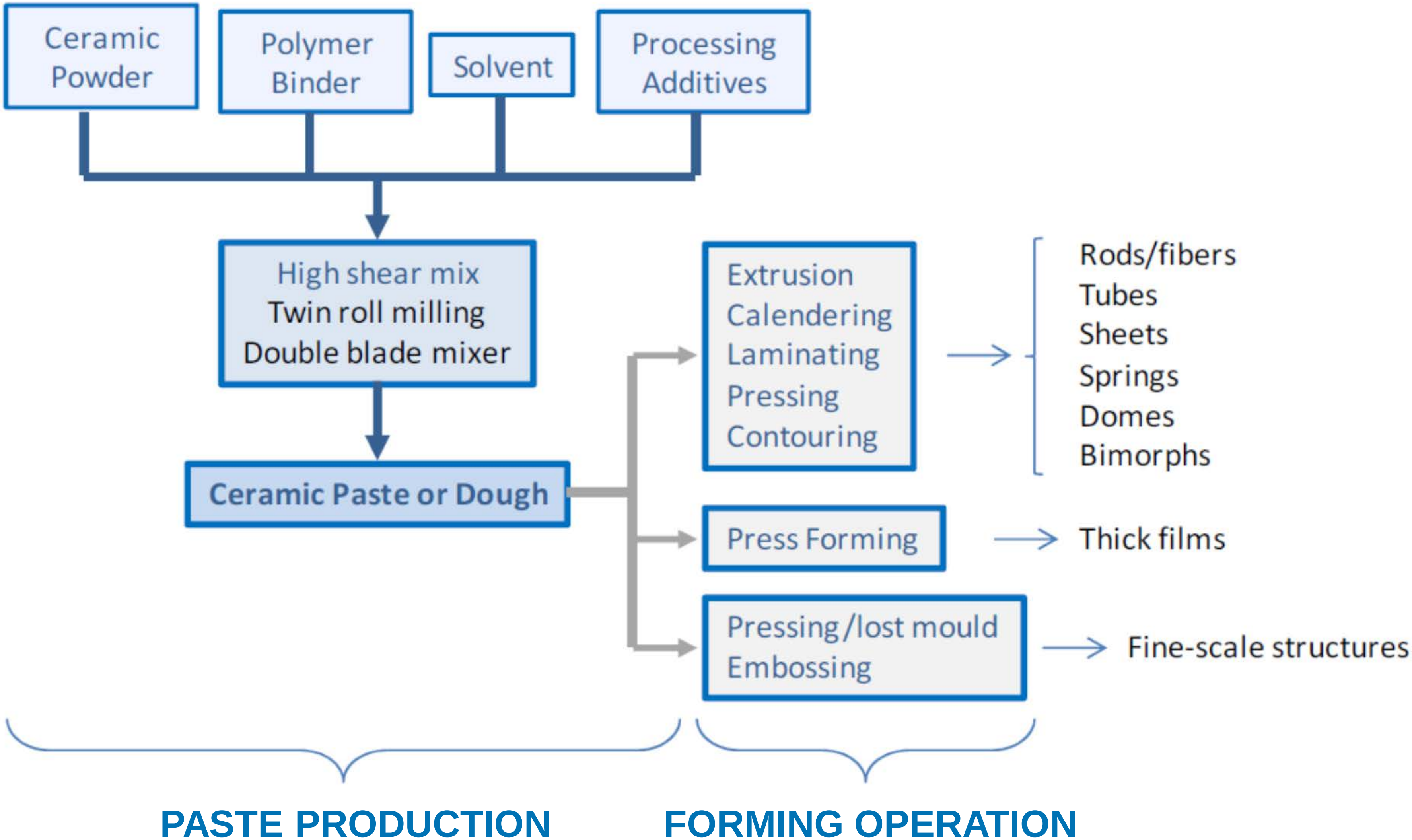
or

<u>Two Step process:</u>
(i)Hot press backing,
(ii)Bonding backing to ceramic

Boron Carbide: manufacturing methods

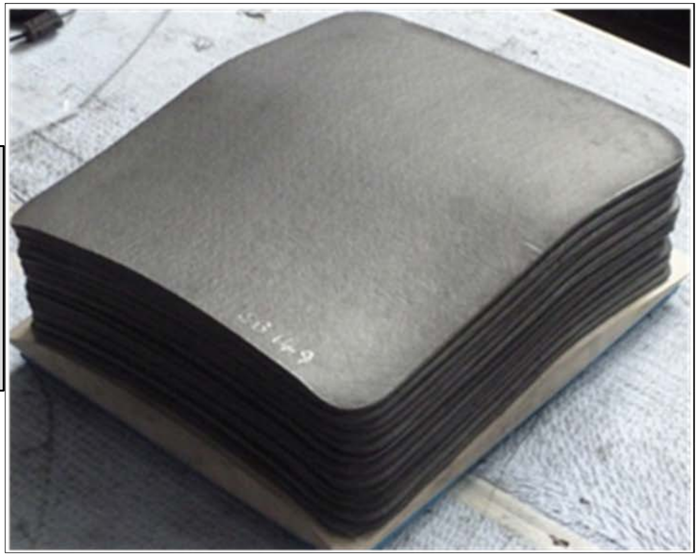
- Hot pressing (HP)
- Reaction bonding/sintering
- Viscous Plastic Processing (VPP), and Pressureless Sintering (PS)

Viscous Plastic Processing of B_4C



Viscous Plastic Processing of B_4C

A stack of Type C tiles for HAPs



Shapely, well-fitting helmet upgrade

Shoulder, or Upper Arm, hard armour

Example of 3D corner piece

ISB29 paper

- Validation of the new VPP boron carbide material in a conventional six-shot Level III+ HAP, via comprehensive ballistic test program

- Development of a new, lightweight three-shot Level III+ HAP

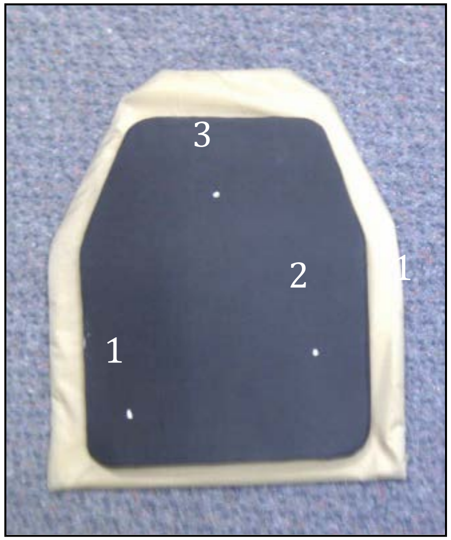
- The material science behind the development of a new VPP/PS boron carbide armour material specification

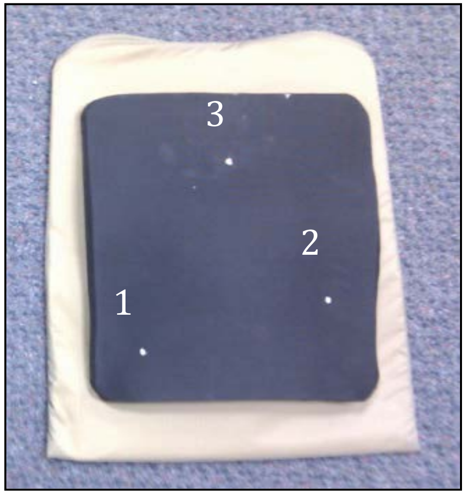
Conventional 6-shot L3+ HAP

- VPP v. HP Boron Carbide HAPs (SAPIs)
- ~100 HAPs used in comparison
- V_{PROOF} tested icw a SAI with AD ~ 5kg/m^2
- Each HAP weighed ~1.9kg

Ballistic Test	Threat	HAP #1 [HP B4C]	HAP #2 [VPP B4C]
V-50 of Stand Alone HAP [normalised values]	A	107.9%	107.6%
	B	110.4%	110.5%
	C	114.7%	119.9%
Mean BFS of HAP icw SAI [mm]	A	31.0	31.8
	B	21.4	18.0
	C	21.6	22.1

Newly-designed 3-shot L3+ HAP





- Designed to meet the ballistic requirements of a new test standard: [DEF(AUST)10946]
- Developed a new body shape, with different front and back plate design icw smaller SAIs
- Reduced ceramic content from conventional values of ~75% to 45% (by weight)
- Using VPP/PS tiles, ballistically determined a minimum acceptable density of 2,385 kg/m^3

- **Outcome:**
  - Each HAP weighed ~1.3 - 1.6kg (saving up to 1.2kg)
  - Total thickness < 15mm (less than UHMWPE plate)

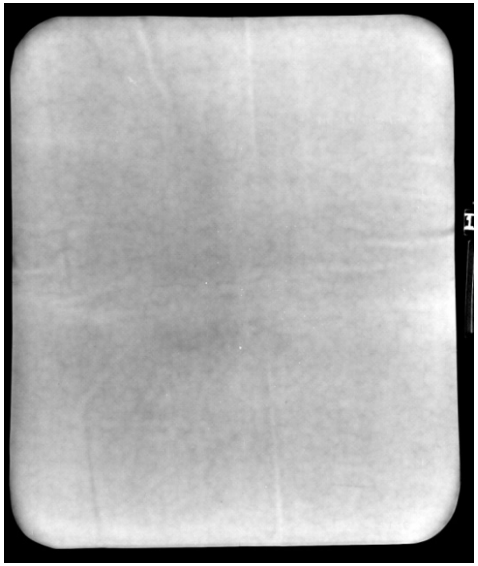
VPP B_4C: supporting material science

- Ballistic performance of ceramic armours governed by dynamic hardness of the ceramic element, and the areal density of the armour system
- For every grade of ceramic, hardness is strongly related to bulk density
- **Areal density = Thickness x Bulk density**

Thickness range:	2.5 to 6.0mm
Thickness control:	+/- 0.2mm
Bulk density:	2,385 to 2.405 kg/m^3

Bulk density measurements

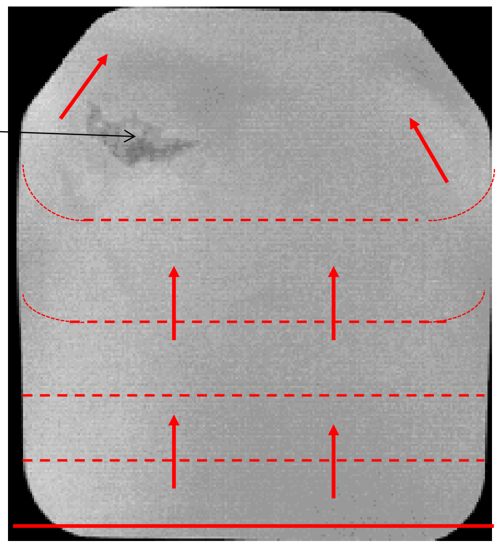
HR Digital X-ray of **VPP B_4C**



Overall density of product, using boiling water method to AS 1774.5, 2001 to an accuracy of +/- 10g/m^3

Area of incomplete fill leading to a large area of unsintered material

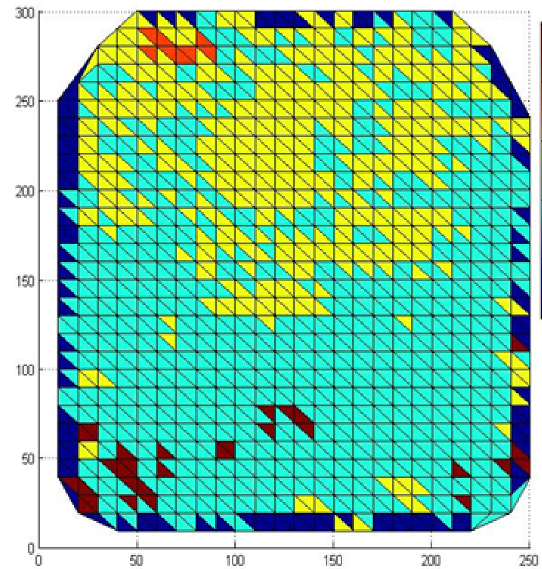
HR Digital X-ray of **RS SiC**



Envisaged direction of flow

Envisaged flow front of liquid silicon

Level of molten silic in furnace



US inspection technique for **RS SiC**

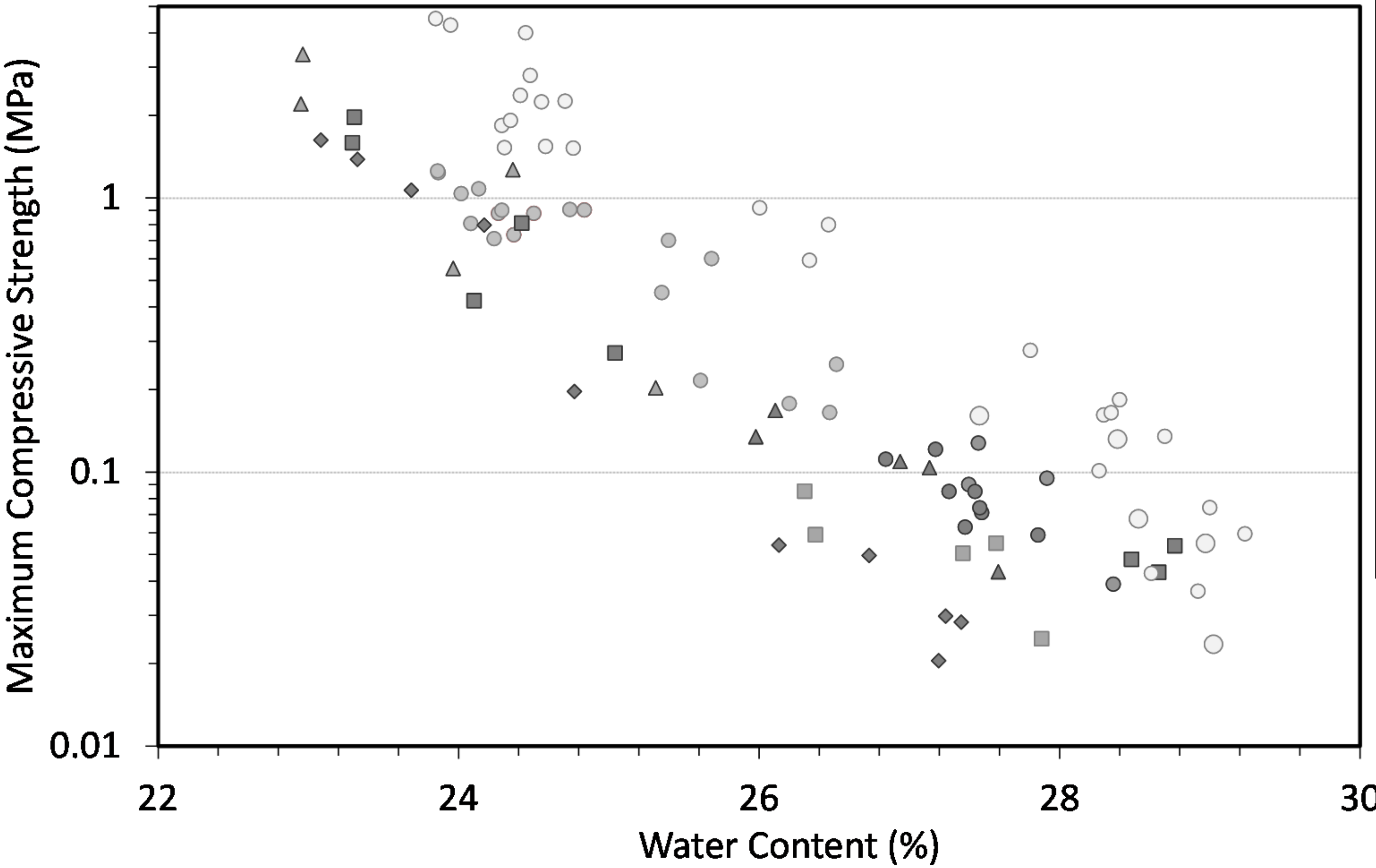
Ref. 10: Crouch et al, 2015

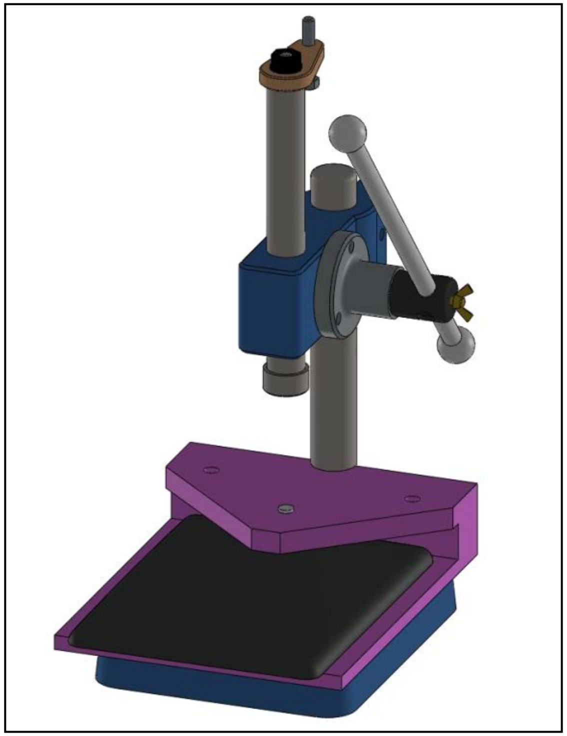
VPP B_4C: ceramic powder

- B_4C powder sourced, as bi-product from abrasives industry
- Composition highly specified
- d_{50} = 2.5 to 3.7 µm
- Surface areas = 2.0 to 5.0 $m^2.g^{-1}$

VPP B_4C: ceramic paste rheology

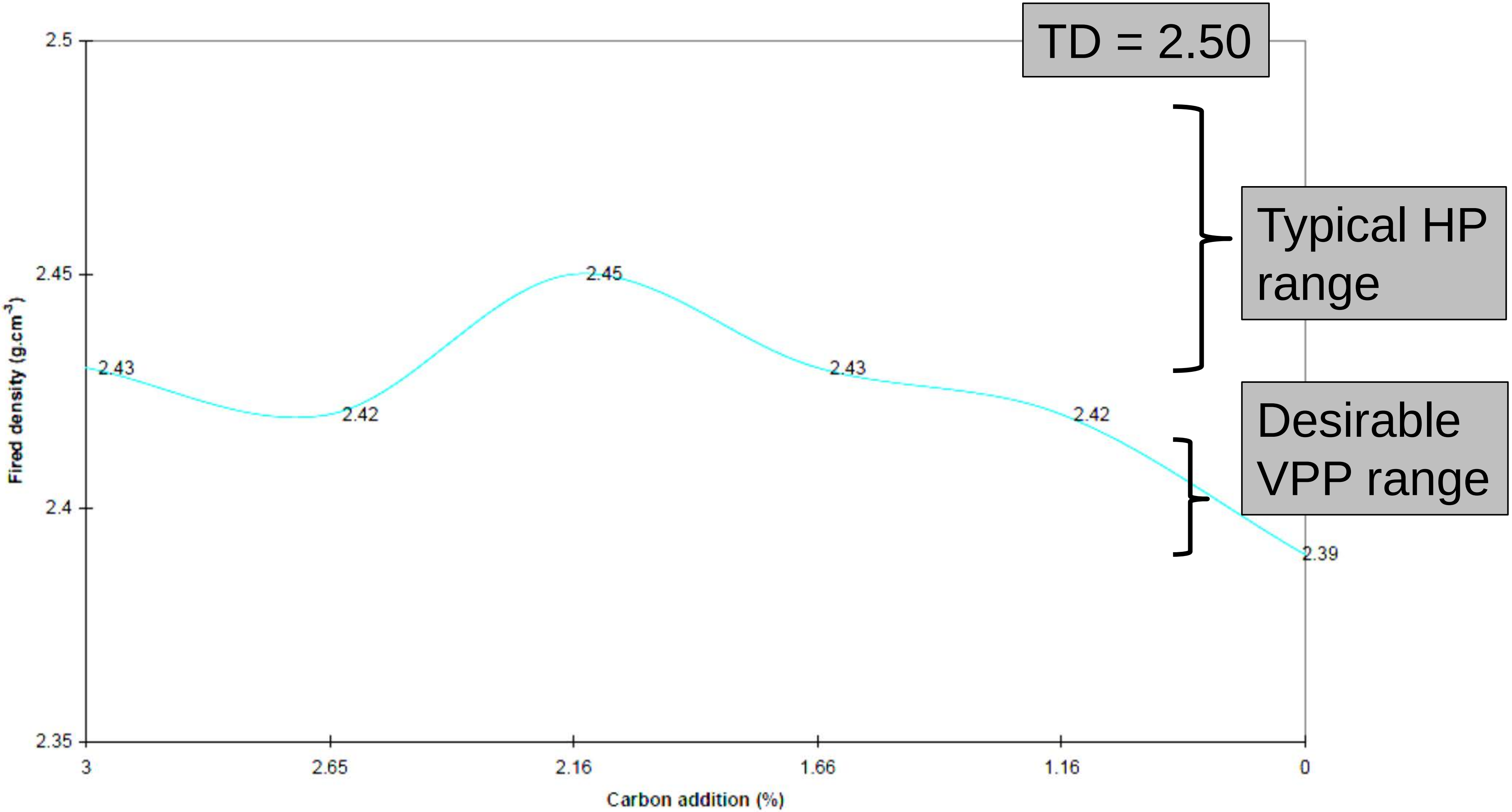
Compression data for 20mm diameter cylinders of paste



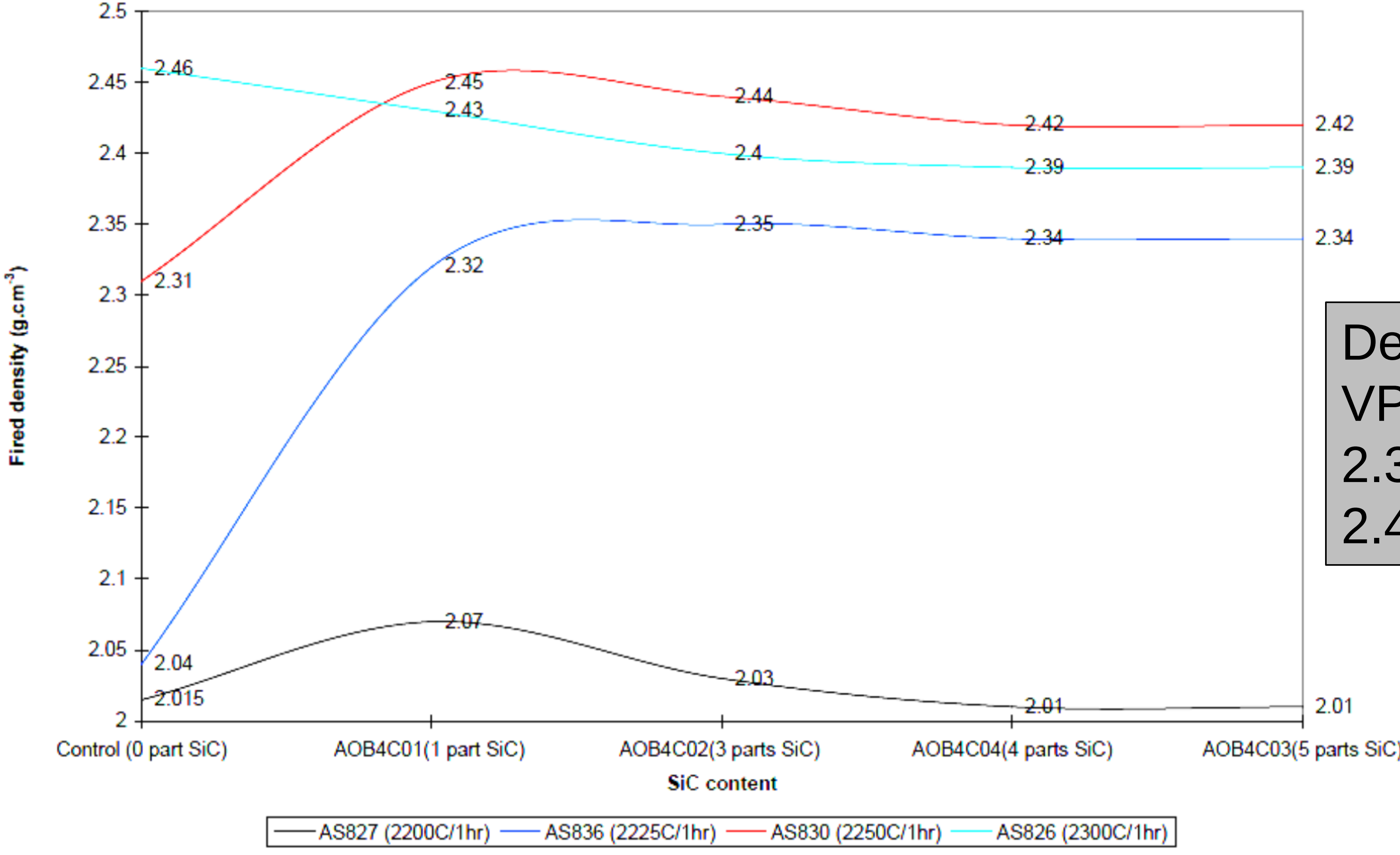


Penetrometer, designed for production environment

VPP B_4C: effect of sintering aids (C)



VPP B_4C: effect of sintering aids (SiC)



Desirable VPP range: 2.385 to 2.405 g/cc

VPP B_4C: shape control




- Stackable items
- Patentable IP related to shaping techniques
- Anisotropic shrinkage:
  X, Y: 15-18%
  Z: 22-25%
- Close control over powder chemistry, paste formulation, and water content.

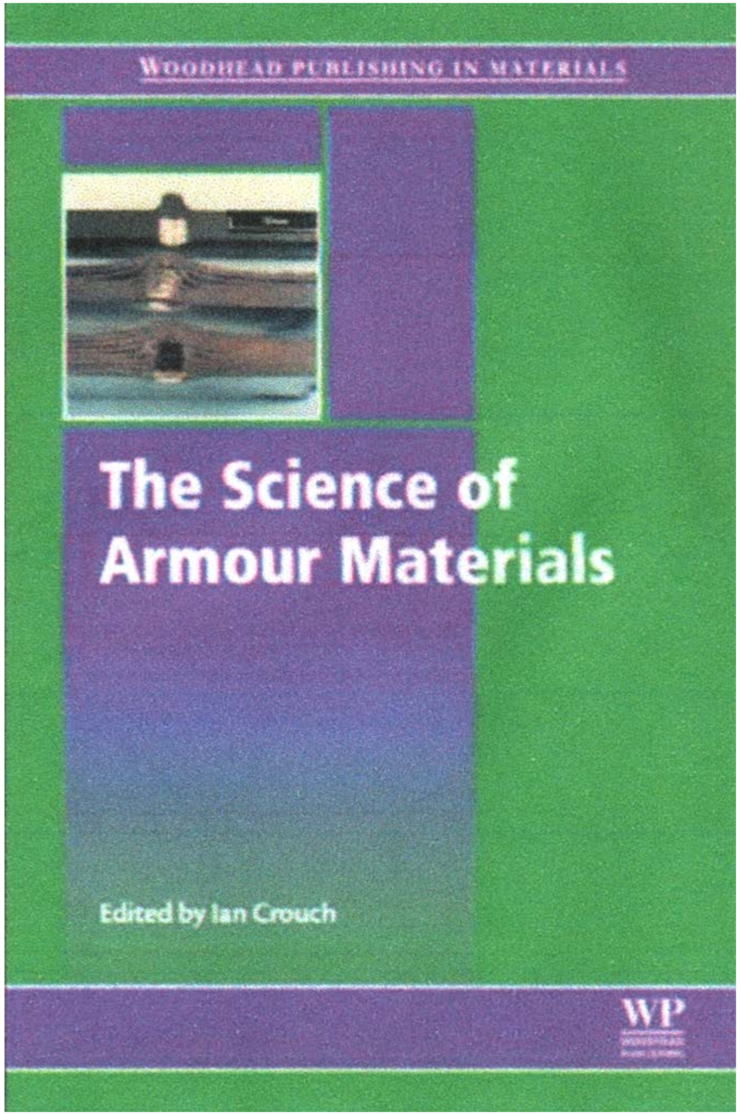
Project outcomes

- A well understood set of material processing parameters for VPP B_4C
- A unique combination of ceramic processing steps to produce thin, shapeable, armour products to tight tolerances
- The establishment of a commercial process, with an initial production run of ~3,500 breastplate tiles
- Development of a new, three-shot lightweight L3+ plate at ~1.5kg

The Science of Armour Materials

Reference 3:
Chapter 7

Reference 4:
Chapter 5



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AUDIENCE

Final-year undergraduates, post-graduates, post-doctorates, research scientists, defence engineers, R&D managers, and senior defence personnel.